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Air Inleakage Testing at Crystal River Unit 3

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ABSTRACT

In order to assess the amount of air inleakage into the Control Complex Habitability Envelope (CCHE) at the Crystal River Unit 3 Nuclear Generating Station, tracer gas tests were performed during October 1997 and again in September 1999. The CCHE consists of a six-story structure that is located physically between the turbine building and the auxiliary building. In case of either a High Rad or Toxic gas event, the emergency ventilation system isolates and enters a recirculation mode.

Because of the physical extent and location of the CCHE, air inleakage testing was undertaken only after the adjacent ventilation systems were configured to provide a minimum of 0.125 in. w.g. across the CCHE. Inleakage data generated at this differential pressure condition were used to constrain a parametric inleakage calculation. Allowable inleakage values were extrapolated to a differential pressure of 0.2 in. w.g. across the CCHE. Dose analyses were calculated assuming this operating condition was bounding.

Air inleakage rates were inferred using procedures based on the methodology described in ASTM Standard E741-93 "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution". Sulfur hexafluoride (SF6) was used as the tracer gas. Sulfur hexafluoride concentrations were determined using measurement specific analyzers optimized for detection of SF6.

In 1997, the air inleakage of the CCHE was measured as 439 +/- 17 CFM in the Toxic Gas Mode, and as 442 +/- 20 CFM in the High Rad Mode. In 1999, the air inleakage of the CCHE was measured as 501 +/- 15 CFM in the Toxic Gas Mode, and as 450 +/- 13 CFM in the High Rad Mode.

To our knowledge, these data represent the first retest of Control Room Envelope air inleakage using tracer gas techniques. The measured inleakage was unchanged for the High Rad mode but increased 14% for the Toxic Gas Mode.

1.0 INTRODUCTION

In order to assess the amount of air inleakage into the Control Complex Habitability Envelope (CCHE) at the Crystal River Unit 3 Nuclear Generating Station, tracer gas air inleakage tests were performed during October 1997 and again in September 1999. The CCHE consists of a six-story structure that is located physically between the turbine building and the auxiliary building. In case of either a High Rad or Toxic gas event, the emergency ventilation system isolates and enters a recirculation mode.

2.0 TRACER GAS TEST TESTING

There are three principal tracer gas techniques for quantifying airflow rates within a structure; namely, the tracer concentration decay method, the constant injection method, and the constant concentration method. All three of these techniques are incorporated in the most recent revision of ASTM Standard E741-93 "Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution" (ASTM, 1993, Lagus & Grot, 1996).

To interpret data resulting from a tracer gas test, one employs a mass balance of a tracer gas released within the volume under test. Assuming that the tracer gas mixes thoroughly within the structure, the mass balance equation is,

$$V \ dC(t)/dt = S(t) - L(t)C(t) \qquad (1)$$

where V is the test volume, C(t) is the tracer gas concentration (dimensionless), dC(t)/dt is the time derivative of concentration, L(t) is the volumetric airflow rate into the test volume, S(t) is the volumetric tracer gas injection rate, and t is time. The outdoor tracer gas concentration is usually assumed to equal zero.

The simplest tracer gas technique is the tracer concentration decay method. After an initial tracer injection into the test volume, there is no source of tracer gas, hence S(t) = 0 and assuming A is constant, a solution to equation (1) is;

$$C = C_0 \exp(-A \cdot t) \qquad (2)$$

where C_0 is the concentration at time t=0.

This method requires only the measurement of relative tracer gas concentrations, as opposed to absolute concentrations, and the analysis required to determine A is straightforward. In use, equation (2) is often recast to the following form;

$$\ln C = \ln C_0 - A \cdot t \qquad (3)$$

In practice one obtains a series of concentration versus time points and then performs regression analysis on the logarithm of concentration versus time to find the best straight line fit to the form of the equation given by equation (3). The slope of this straight line is A, the air exchange rate.

The air exchange or infiltration rate, A, is given by A(t) = L(t)/V. The units of A are air changes per hour (h^{-1} or ACH). The value of A represents the volume normalized flowrate of "dilution air" entering the volume during the test interval. Note that this "dilution air" can be actual outside fresh air or, more generally, it can be air whose origin is not within the test volume.

The air inleakage testing at Crystal River Unit 3 Nuclear Generating Station used the tracer concentration decay method. The essentials of the test method are illustrated schematically in Figure 1.

As depicted in Figure 1, the natural logarithm of the tracer concentration decreases linearly with time. The slope of this line is A, the air exchange rate. To calculate the air inleakage rate, one must have independent knowledge of the CCHE volume from which,

$$L = A \cdot V \qquad (4)$$

The results obtained with this technique are exact only for a well-mixed volume, (i.e. concentration at a given time is the same throughout the test volume). Otherwise, the results will be subject to errors, with the magnitude of these errors depending on the extent of the departure from homogeneity. The tracer concentration data obtained within the Crystal River Unit 3 CCHE and used in the calculation of the air exchange rates demonstrate that the tracer gas was well mixed, hence equation (2) could be applied.

In the following, the total uncertainty of each inleakage measurement is calculated using the prescription provided in ANSI/ASME Standard PT 19.1-1985 "Measurement Uncertainty" (ANSI, 1990) and represents 95% confidence limits. This analysis is based upon equation (4) and uncertainties for all derived and measured quantities are incorporated into the analysis.

3.0 CONTROL COMPLEX HABITABILITY ENVELOPE TEST CONFIGURATION

The Control Complex Habitability Envelope (CCHE) at the Crystal River Unit 3 Nuclear Power Plant consists of a six-storey structure that is physically located between the turbine building and the auxiliary building. A schematic view of the CCHE is provided in Figure 2.

For the purposes of air inleakage testing, the CCHE consists of seven levels. The Mechanical Equipment Room is located on the 164-foot level. The Control Room occupies the 145-foot level. The Cable Spreading Room is located on the 134-foot level.

The EFIC Rooms are located on the 124-foot level. The Battery Rooms occupy the 108-foot level. The entire Stairwell that allows access to each of these levels runs from an elevation of 195 feet (roof level is at 186 feet) down to 95 feet. A roof entrance vestibule at the top of the stairwell and a similar vestibule at the bottom constitute the additional two levels of the CCHE. The volume of the entire CCHE is 364,922 cubic feet.

The Crystal River Unit 3 CCHE HVAC system is a neutral system with relation to outside environment. On a CCHE HVAC actuation, the outside makeup air is isolated through redundant bubble tight dampers. Through operator action, the CCHE HVAC is aligned to the Emergency mode and the entire CC volume is recirculated through large 45,000 CFM filtration banks. It is important to note that the Mechanical Equipment Room, which houses the fans, filters and ductwork, is located *inside* the CCHE.

The CCHE is located physically between the Auxiliary Building and the Turbine Building. The Turbine Building is open to atmosphere and utilizes up to nine supply fans to cool the area resulting in a slightly positive Turbine Building. The Auxiliary Building is designed to operate at a negative pressure (at approximately 1/8 in. w.g.) to assure that any ECCS system leakage is captured within the Auxiliary Building and its charcoal filters. The net effect of this geometry on the CCHE is to create a potential differential pressure across the CCHE driven by the Auxiliary Building and the Turbine Building Ventilation Systems.

Tracer gas testing was performed with at least 1/8 in. w.g. differential pressure across the CCHE and was a test requirement requested by NRC. The actual differential pressure during testing was 0.17 in. w.g. Maintenance of such a differential pressure assured that sufficient motive force was present to force non-CCHE air (leakage) through the CCHE. The flow path for this leakage flow was Turbine Building to CCHE to Auxiliary Building. Testing the CCHE at this differential pressure also helped to minimize the external effects of wind on the CCHE.

The Turbine Building HVAC Supply and the Auxiliary Building Ventilation Systems are non-safety related and non-ES powered. On a LOCA without LOOP, the Turbine Building HVAC Supply and the Auxiliary Building Exhaust would remain in service. The Auxiliary Building Supply System would likely trip on a high radiation alarm. The result is a condition with maximum negative pressure in the Auxiliary Building with a slightly positive pressure in the Turbine Building. Such an accident scenario creates maximum differential pressure of approximately 0.2 in. w.g. across the CCHE boundary. This maximum value was used as an upper limit for dose analysis and allowable in-leakage limits. For the typically analyzed LOOP/LOCA, operator dose from in-leakage would be much less due to the lack of a driving force across the CCHE.

Inleakage data generated at the 0.17 in. w.g. differential pressure condition from the 1997 testing were used to constrain a parametric inleakage calculation. Allowable inleakage values were extrapolated to a maximum differential pressure of 0.2 in. w.g. across the CCHE. Dose analyses were calculated assuming this operating condition was bounding.

A plot of the parametric calculation is provided on Figure 3. On this figure, the ratio of maximum differential pressure (0.2 in. w.g.) versus test differential pressure is plotted on the X-axis versus the measured in-leakage on the Y-axis. Also shown is the line corresponding to GDC 19 limit values. The difference between the two lines provides a measure of the habitability margin.

4.0 AIR EXCHANGE RATE DATA

Ventilation diagrams for Toxic Gas Mode and the High Rad Mode are shown in Figures 4 and 5. Note that between the 1997 testing and the 1999 testing the isolation dampers AHD 1C, 1E, 2C, 2E, 12 and 12D were replaced with bubble tight dampers. During the 1997 testing, the isolation damper location was blanked off.

Because of the physical extent and location of the CCHE, as well as the requirements of pre-test inleakage calculations, air inleakage testing was undertaken only after the adjacent ventilation systems (Turbine Building and Auxiliary Building) were configured to provide a differential pressure of 0.17 in. w.g. across the CCHE.

An individual air inleakage test was performed with the CCHE emergency ventilation system in either the Toxic Gas Mode or the High Rad Mode. For the Toxic Gas Mode test Supply Fan 17B and Return Fan 19B were operating. For the HiRad Mode test Supply Fan 18A and Return Fan 19A were operating. To begin either test, an SF6 in nitrogen mixture possessing a concentration of approximately 700 ppm was injected into the suction side of the appropriate Air Handling Unit. Injection continued for 90 minutes. To minimize interference with normal plant operations, testing was undertaken on the backshift with tracer gas injection commencing around 2100 hours each evening.

During the actual testing, portable fans were used to assist tracer gas mixing and distribution within the Mechanical Equipment Room, the Cable Spreading Room, the Control Room level bathrooms, and the Stairwell. Eight portable mixing fans were arranged within the Mechanical Equipment Room, twelve portable fans were emplaced at successive levels within the Stairwell, and two portable fans were positioned to circulate room air to the two bathrooms on the Control Room level. Three portable fans were positioned on the south half of the Cable Spreading Room. In addition, during the actual testing, two large capacity halon system circulating fans located on the north side of the Cable Spreading Room were activated.

All internal doors on the 108, 124, 134 levels as well as the two bathroom doors on the 145' level were propped open during the testing to assist in the mixing of the tracer gas. The main access door the Control Room remained closed except for normal ingress and egress. In addition, the stairwell door to the Elevator Mechanical Equipment Room (which is itself within the CCHE) was propped open during the test and a single portable fan was positioned to circulate air into this room from the adjacent stairwell landing.

No additional mixing fans were used in the Main Control Room. Previous experience in other nuclear power plant Control Room Envelopes has shown that ventilation flows into well ventilated rooms are sufficient to mix tracer over the time interval that elapsed prior to initiation of sampling. Tracer concentration data obtained in the Battery and the EFIC rooms as well as the main Control Room confirm that good mixing was induced by the air flows created by the emergency ventilation system thereby obviating the need for mixing fans in these areas.

Access to the CCHE is normally through vestibules door located at levels 95, 124, 145, 153 and 186. The 186 level vestibule actually provides access to the roof. Redundant vestibule doors are provided to minimize door-opening inleakage during an accident condition. During a test, access to the CCHE was limited to a single door on the 145' level. All other access doors were physically and administratively removed from use during the course of the testing.

In addition, during testing one vestibule door at each level was propped open to ensure that only a single access door provided an inleakage barrier. Note that Crystal River Unit 3 does not take credit for the additional vestibule doors in their accident analyses.

Sampling for tracer gas commenced sixty minutes after the cessation of tracer gas injection. Tracer gas samples were collected from 43 different locations throughout the CCHE at 60-minute intervals. Good mixing of the tracer within the tested volume is required in order to use the calculational framework outlined in Section 2. Therefore, a number of samples from diverse spatial locations were obtained on each floor of the CCHE. The tracer sample locations for the inleakage test program at Crystal River Unit 3 are described in Table 1.

Sampling continued for six hours and generated in excess of 300 samples for analysis. SF6 analyses were performed onsite using a pair of measurement-specific gas analyzers optimized for SF6 detection. Each monitor was calibrated daily immediately prior to test initiation.

By demonstrating that the measured concentrations deviated little from the mean, it was experimentally demonstrated that good mixing was achieved. Hence, the calculations outlined in Section 2 could be undertaken with confidence.

The measured air exchange rates for the 1997 tests are provided in Table 2, while the corresponding data for the 1999 testing are provided in Table 3. The air inleakage rates in these tables were converted to CFM assuming a CCHE volume of 364,922 Cubic Feet using equation (4). Calculation of measurement uncertainty associated with the measured inleakage values in Tables 2 and 3 is performed using the prescription found in ANSI Standard PT19.1 (ANSI, 1991). Plots showing the mean tracer concentration values versus time along with the regression fit to the data are provided in Figures 6 through 9.

As can be seen from these figures, the regression line fits the measured concentration data rather well.

A summary of mean tracer concentration values for the CCHE at each sampling interval is provided in Tables 4 for the 1997 tests and Table 5 for the 1999 tests. The standard deviation of all tracer measurements at a given measurement interval is shown also. The standard deviation is a statistical measure of how much a collection of measurements differs from the mean of the collection. The smaller the standard deviation, the closer individual values in the collection are to the mean. Inspection of Tables 4 and 5 discloses that at each sample time, the standard deviation of the mean concentration ranges from +/- 2.5 % to +/- 6.5 %, thereby confirming that tracer was well mixed throughout the CCHE.
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5.0 CONCLUSIONS

In 1997, the air inleakage of the CCHE was measured as 439 +/- 17 CFM in the Toxic Gas Mode, and as 442 +/- 20 CFM in the High Rad Mode. In 1999, the air inleakage of the CCHE was measured as 501 +/- 15 CFM in the Toxic Gas Mode, and as 450 +/- 13 CFM in the High Rad Mode.

To our knowledge, these data represent the first retest of Control Room Envelope air inleakage using tracer gas techniques. The measured inleakage was unchanged for the High Rad mode but increased 14% for the Toxic Gas Mode. This increase may be due to the fact that the emergency HVAC system was modified slightly after the 1997 testing.

During the 1997 testing, the six isolation dampers were blanked off. After test completion, the existing dampers were replaced with bubble tight dampers. In September of 1999, these dampers were not tested for leakage. One possible explanation for the increased leakage in the Toxic Gas Mode may be actual bypass leakage across one or more of the isolation dampers.

A second possibility is that an access door was not completely closed during the test. Since the CCHE was subjected to a substantial differential pressure, any breach of boundary integrity could result in excess leakage*.

Due to the cost and the complexity of the testing, no time was available to investigate possible contributors to the increased inleakage. Since the measured inleakage was within allowable limits, additional effort could not be justified.

* At 0.17 in. w.g. of differential pressure, it only requires an additional 10 square inches of leakage area to account for an extra 50 CFM of leakage. A seven foot door with a 1/8 inch gap would easily provide sufficient extra leakage area.

6.0 REFERENCES

ASTM, Standard Test Method E 741-95, 1995, "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution", ASTM, Philadelphia, PA

Lagus, P.L. and Grot, R.A., 1996, "Control Room Envelope Unfiltered Air Inleakage Test Protocols", in Proceedings of the 24th NRC/DOE Air Cleaning Conference, Portland, OR.

ANSI, 1990, American National Standards Institute Standard PTC 19.1 "Measurement Uncertainty", American National Standards Institute, New York, NY

Table 1.

Sample Locations for Air Inleakage Testing

Location	Description
MEC	Center of Ventilation Equipment Room (MER)
MESE	Southeast corner of MER
MENE	Northeast corner of MER
MESW	Southwest corner of MER
MENW	Northwest corner of MER
CRLUN	Center of lunch room 145 level
CRENT	Center of entrance corridor outside MCR
CRCLRK	Center of Shift Clerk office on 145 level
NSS	Center of NSS office on 145 level
CRC	Center of Main Control Room (MCR) @ Supervisor Desk
CRSW	Southwest corner of MCR
CRSE	Southeast corner of MCRx
CRNE	Northeast corner of MCR
ST802	Stairwell Landing adjacent to door 802
ELEV	Stairwell landing adjacent to elevator mechanical room
164 LEV	Stairwell landing at 164' level
145 LEV	Stairwell landing at 145' level
134 LEV	Stairwell landing at 134' level
124 LEV	Stairwell landing at 124' level
108 LEV	Stairwell landing at 108' level
95 LEV	Stairwell landing at 95' level
CSNE	Center of northeast quadrant of Cable Spread room
CSNC	Center of north half of Cable Spread room
CSNW	Center of northwest quadrant of Cable Spread room

Table 1 (Cont'd).

Sample Locations for Air Inleakage testing

Location	Description
CSSE	Center of southeast quadrant of Cable Spread room
CSSC	Center of south half of Cable Spread room
CSSW	Center of southwest quadrant of Cable Spread room
EF305	Center of EFIC room 305
EF304	Center of EFIC room 304
EF301	Center of EFIC room 301
EFEN	Center of entrance corridor to EFIC room
EFNW	Center of northwest sub-room of EFIC room 302
EFNE	Center of northeast sub-room of EFIC room 302
EF303N	North center of EFIC room 303
EF303S	South center of EFIC room 303
BA209	Center of Battery room 209
BA208	Center of Battery room 208
BA207	Center of Battery room 207
BA206	Center of Battery room 206
BA204/5	Doorway between Battery room 204 and 205
BA203	Center of Battery room 203
BA202	Center of Battery room 202
BACORR	Center of Battery room entry corridor

Table 2

Air Inleakage Value for 1997 Testing

Parameter	Toxic Gas Mode	High Rad Mode
AIR EXCHANGE RATE (ACH)	0.0721	0.0727
AIR INLEAKAGE RATE (CFM)	439 +/- 17	442 +/- 20

Table 3

Air Inleakage Values for 1999 Testing

Parameter	Toxic Gas Mode	High Rad Mode
AIR EXCHANGE RATE (ACH)	0.0824	0.0740
AIR INLEAKAGE RATE (CFM)	501 +/- 15	450 +/- 13

Table 4

Concentration Mean Values and Standard Deviation-1997 Tests

ELAPSED TIME (hr)	TOXIC GAS MODE MEAN CONC. (ppb)	TOXIC GAS MODE STD. DEVIATION (%)	HIGH RAD MODE MEAN CONC. (ppb)	HIGH RAD MODE STD. DEVIATION (%)
0	42.64	2.5	34.05	3.1
1	39.87	3.0	31.53	2.9
2	37.29	3.3	29.3	3.0
3	34.71	3.0	27.46	2.9
4	31.90	4.2	25.50	2.9
5	29.61	4.2	23.57	3.3
6	27.94	3.6	21.97	3.1

Table 5

Concentration Mean Values and Standard Deviation-1999 Tests

ELAPSED TIME (hr)	TOXIC GAS MODE MEAN CONC. (ppb)	TOXIC GAS MODE STD. DEVIATION (%)	HIGH RAD MODE MEAN CONC. (ppb)	HIGH RAD MODE STD. DEVIATION (%)
0	32.86	5.5	27.06	5.5
1	29.47	3.6	24.80	3.2
2	26.70	5.6	22.86	3.2
3	24.46	5.6	21.17	3.6
4	22.79	3.9	19.72	3.6
5	21.23	6.5	18.43	4.1
6	19.97	5.3	17.36	4.1

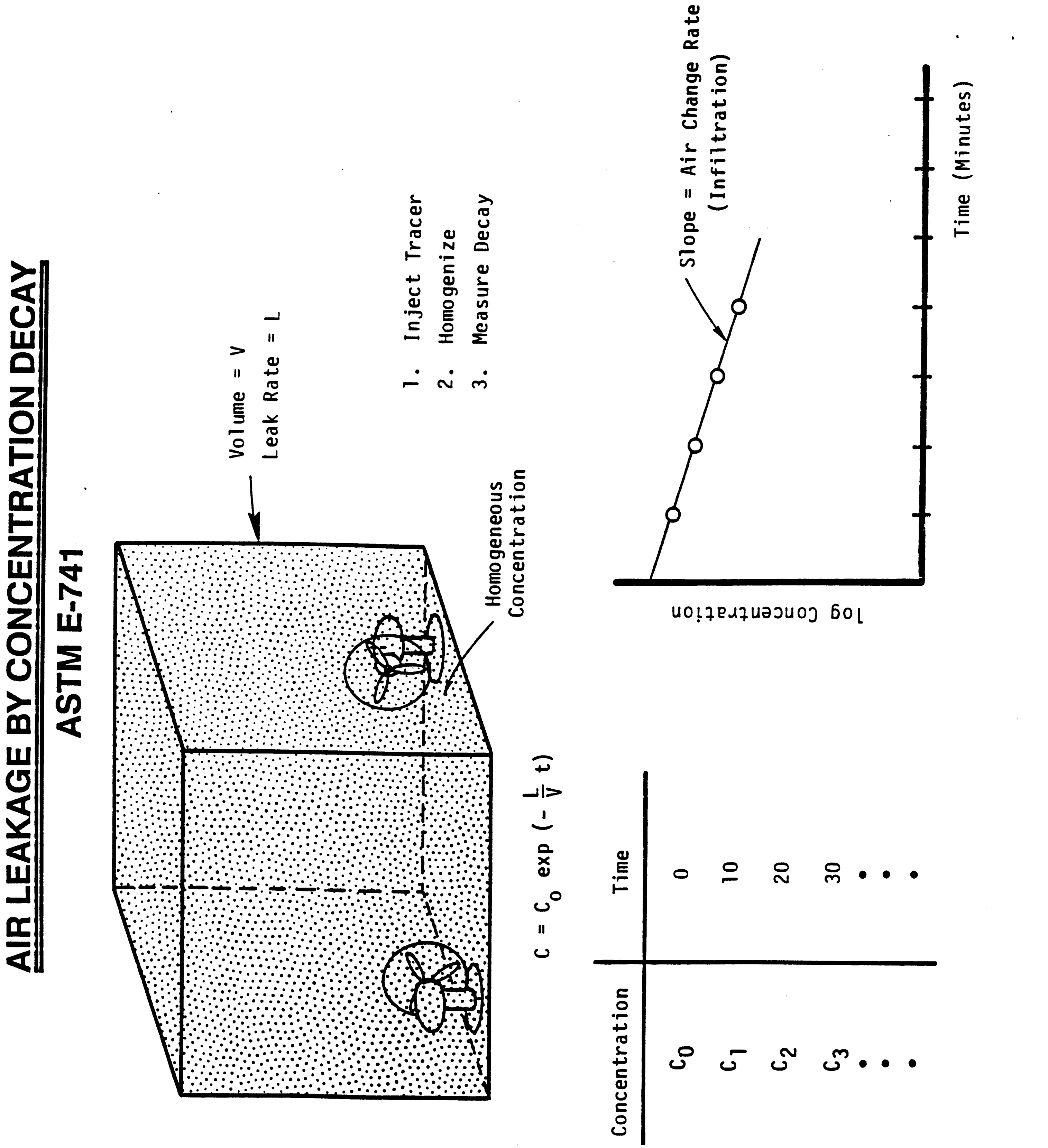

Figure 1. Concentration decay test.

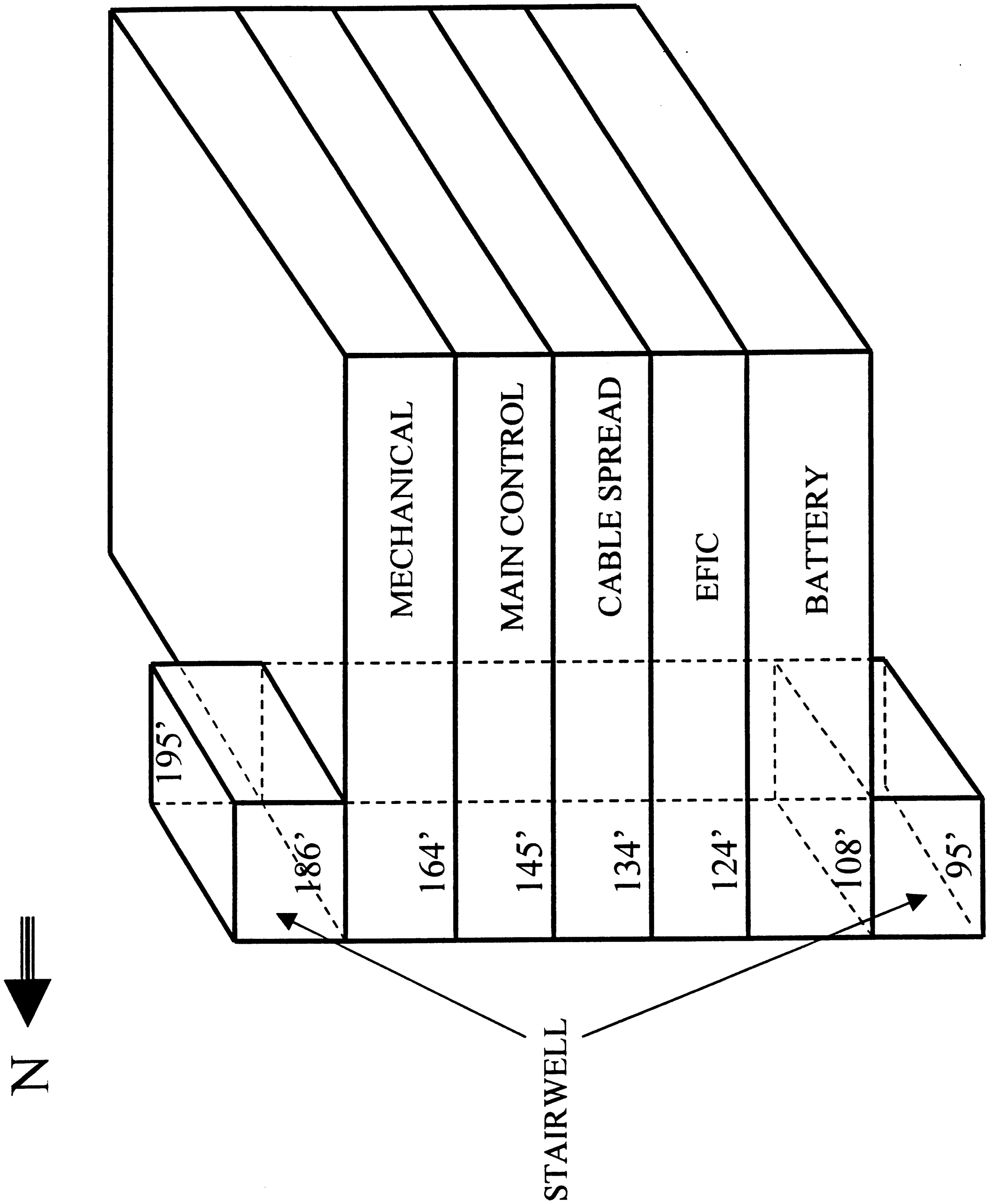

Figure 2. CCHE Configuration.

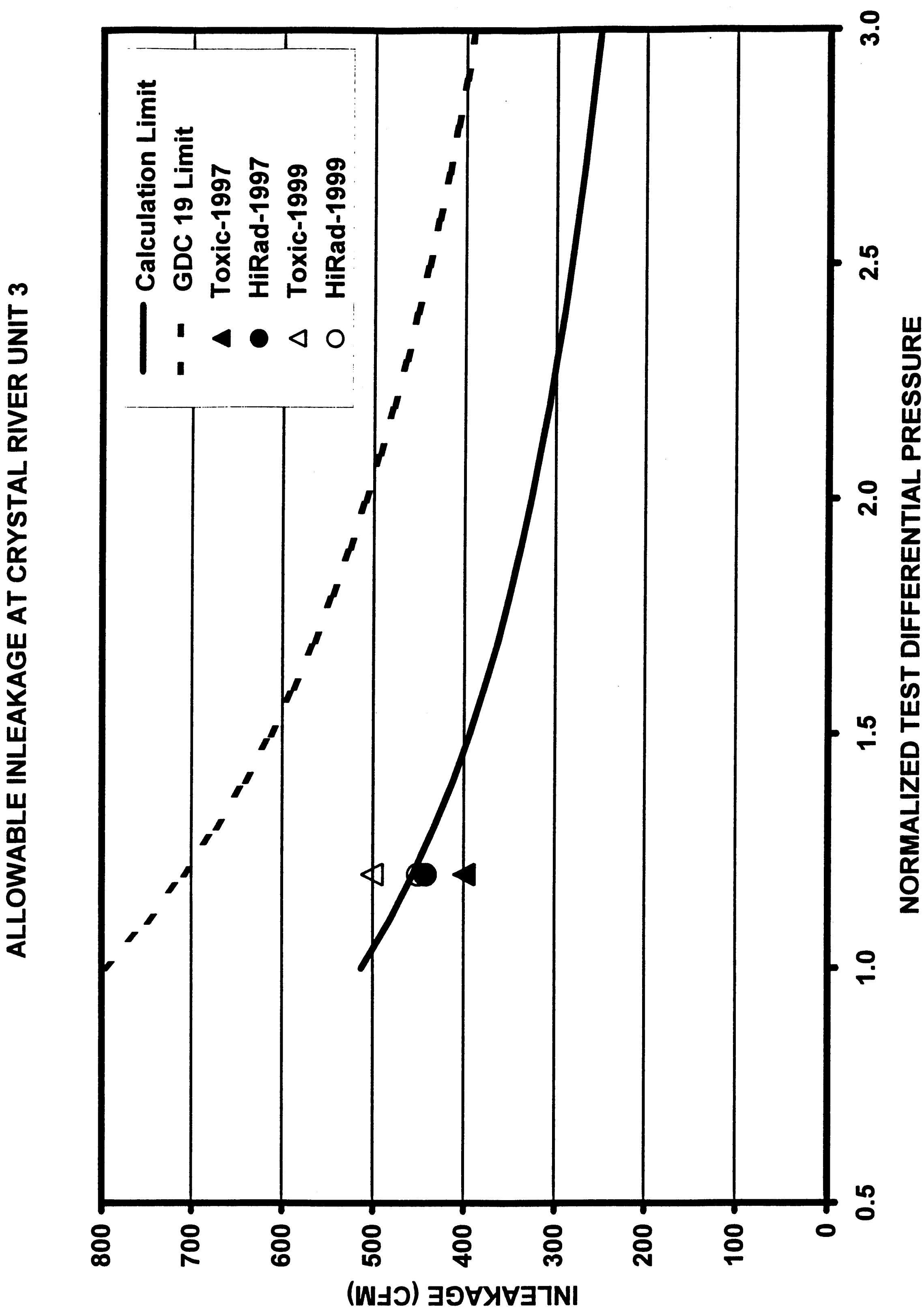

Figure 3. Inleakage Limits for Crystal River Unit 3 CCHE

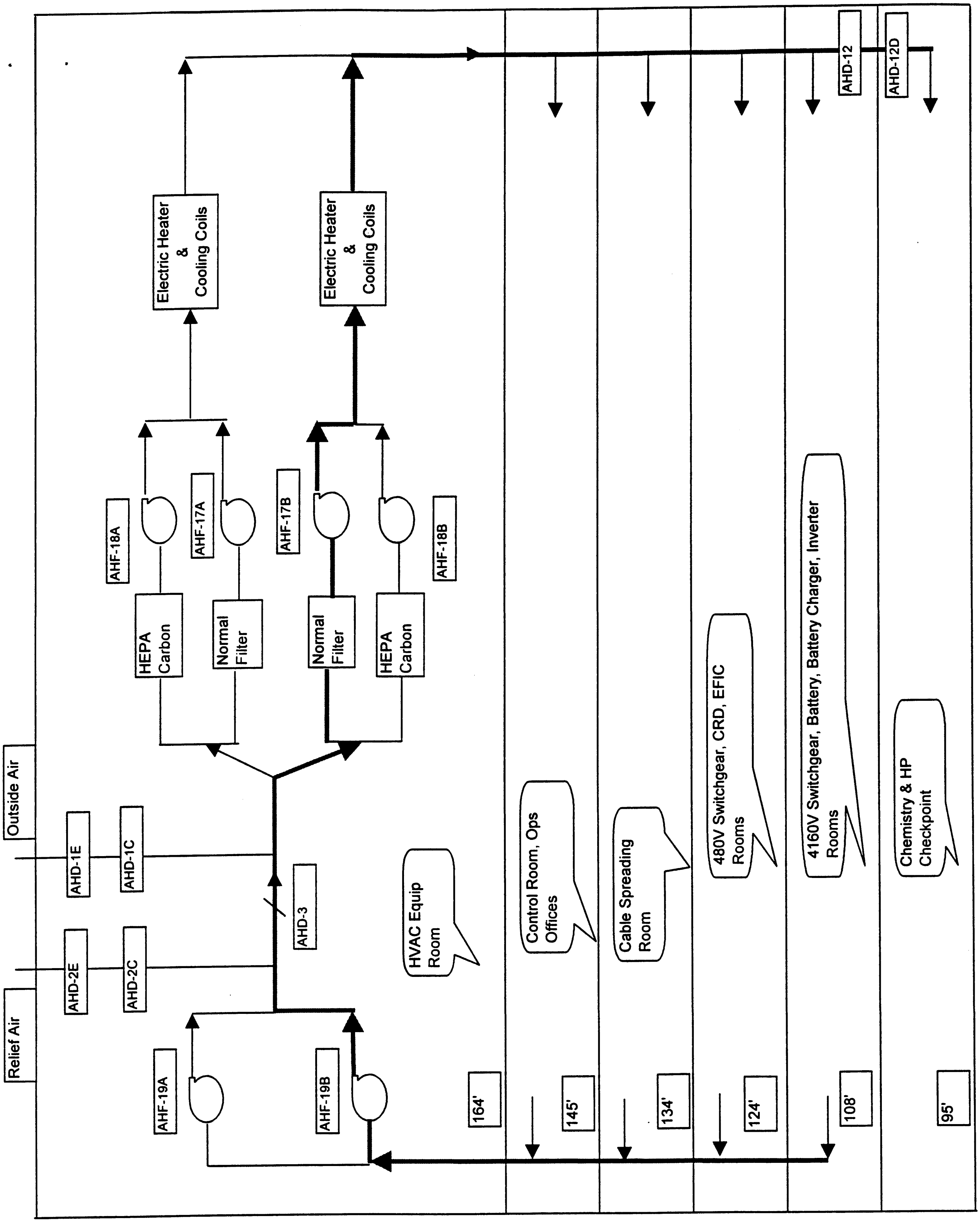

Figure 4. CCHE HVAC in Toxic Gas Mode

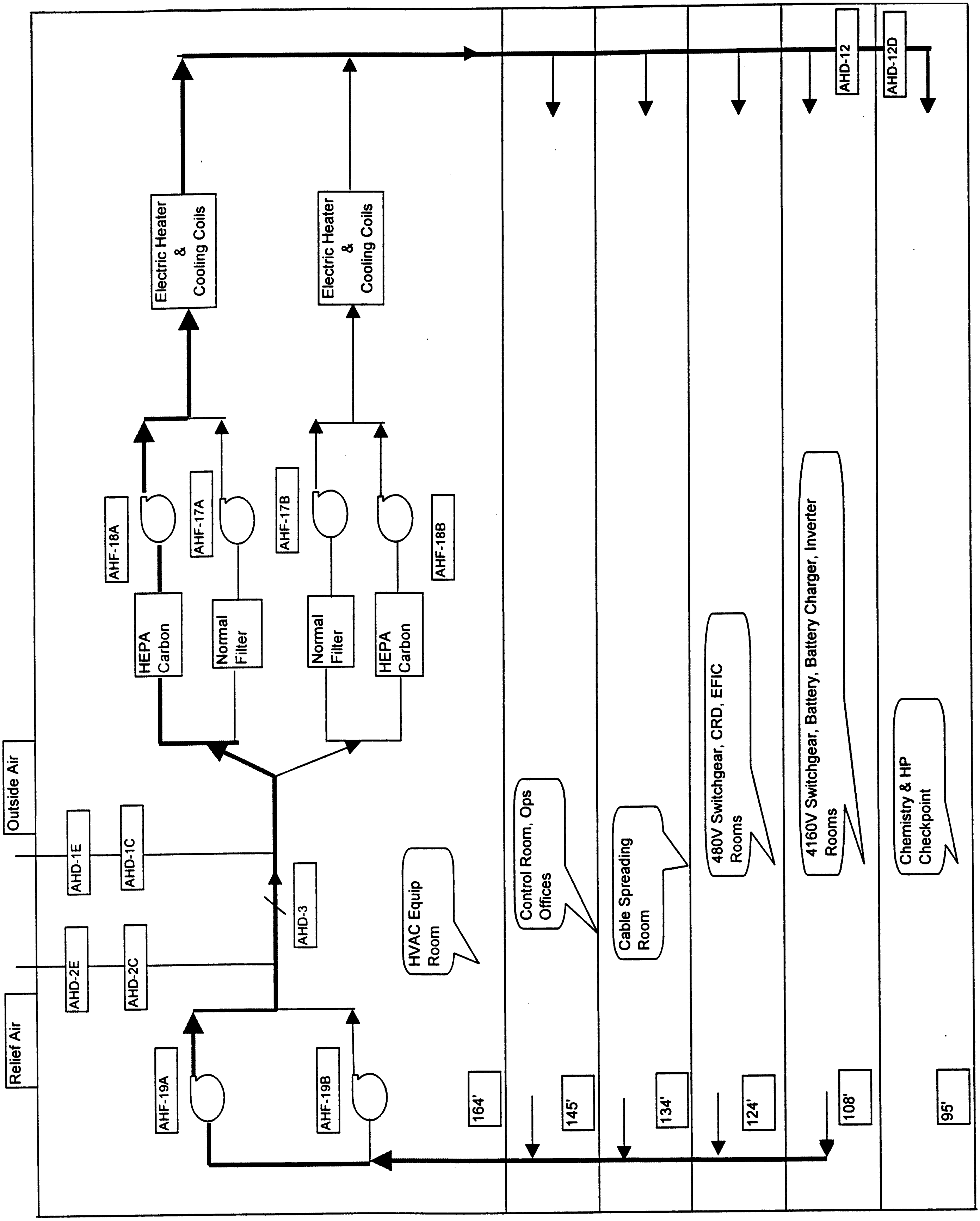

Figure 5. CCHE HVAC in HiRad Mode

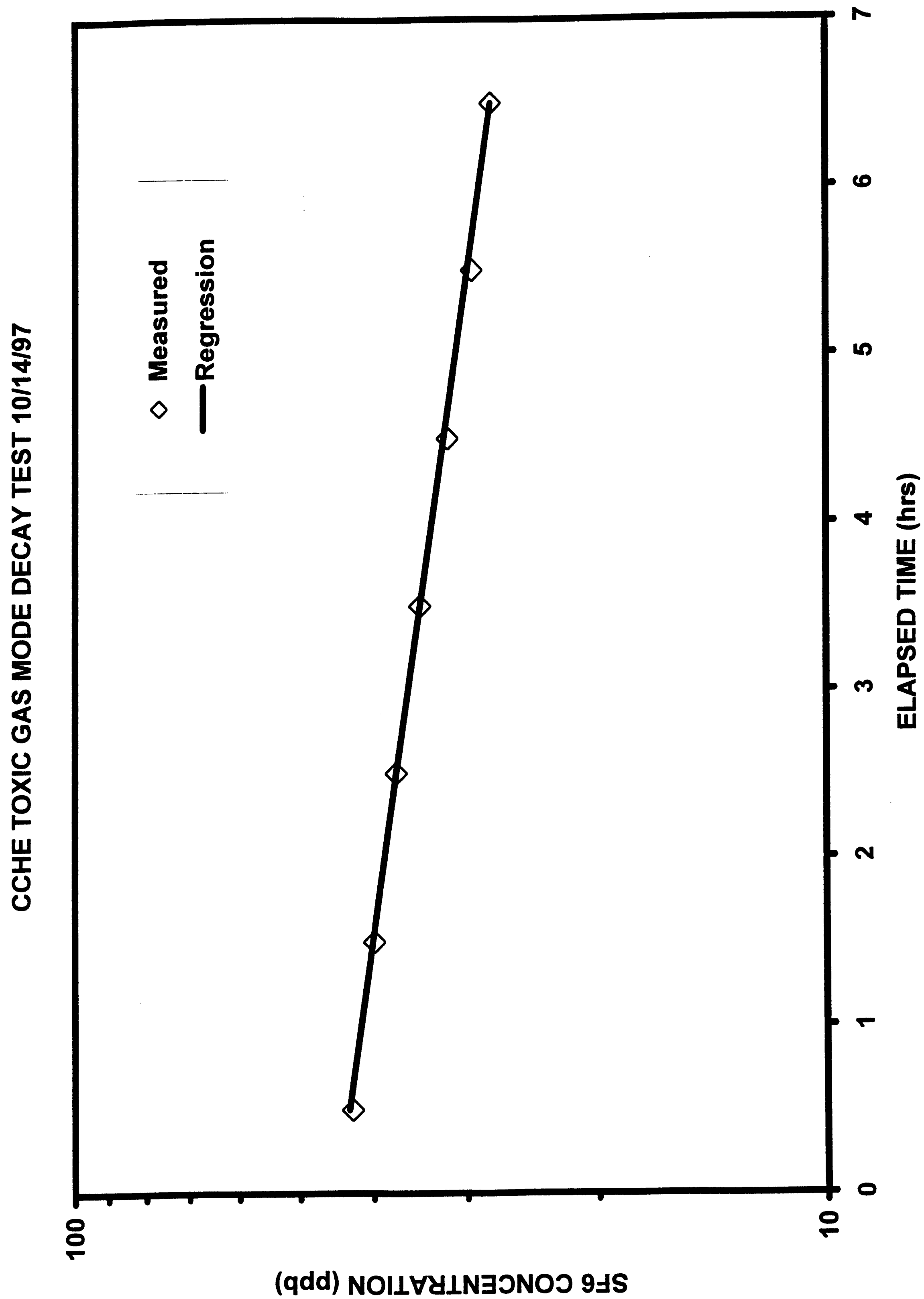

Figure 6. Toxic Gas Mode Tracer Gas Concentration Decay Data 10/14/97

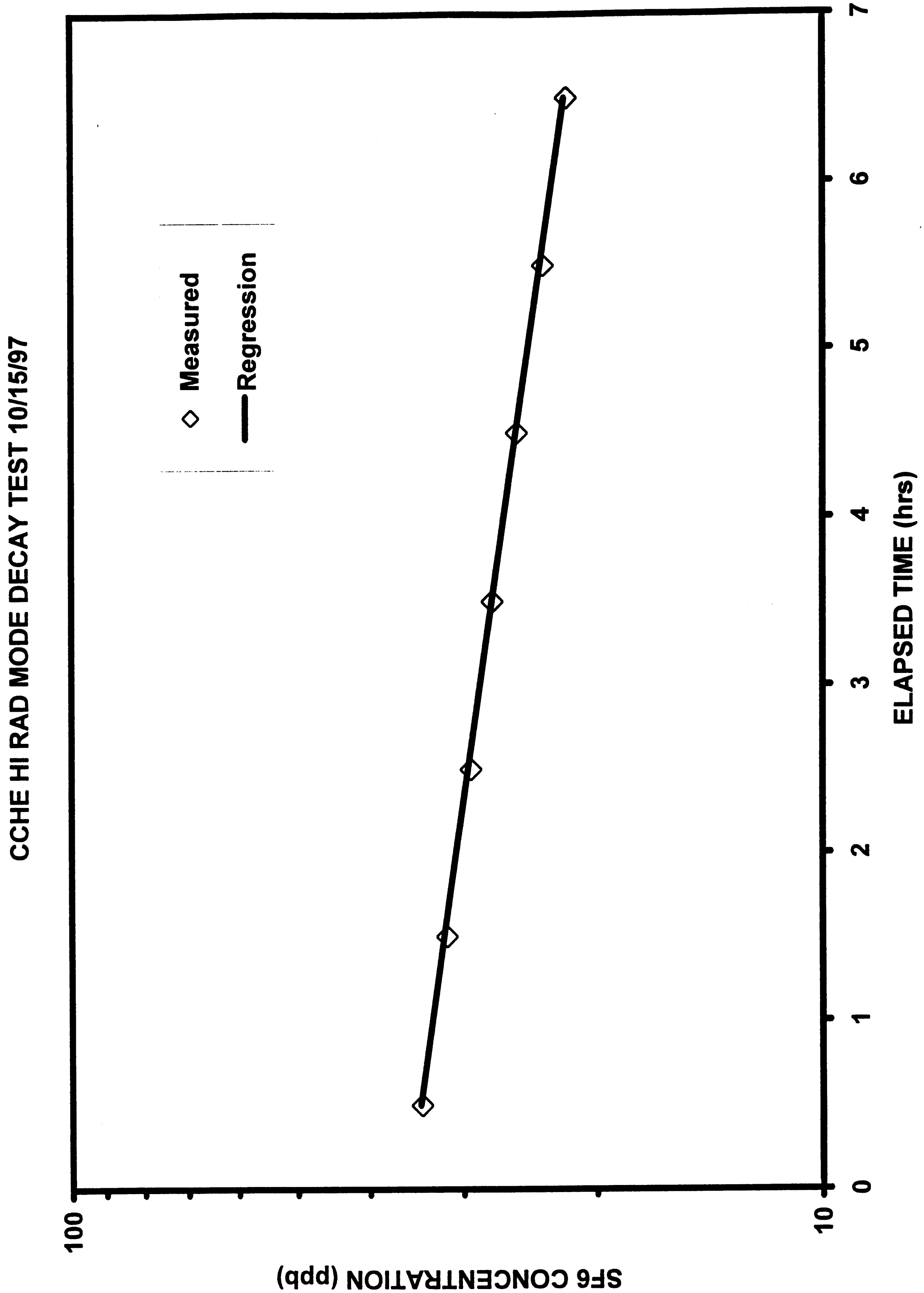

Figure 7. HiRad Mode Tracer Gas Concentration Decay Data 10/15/97

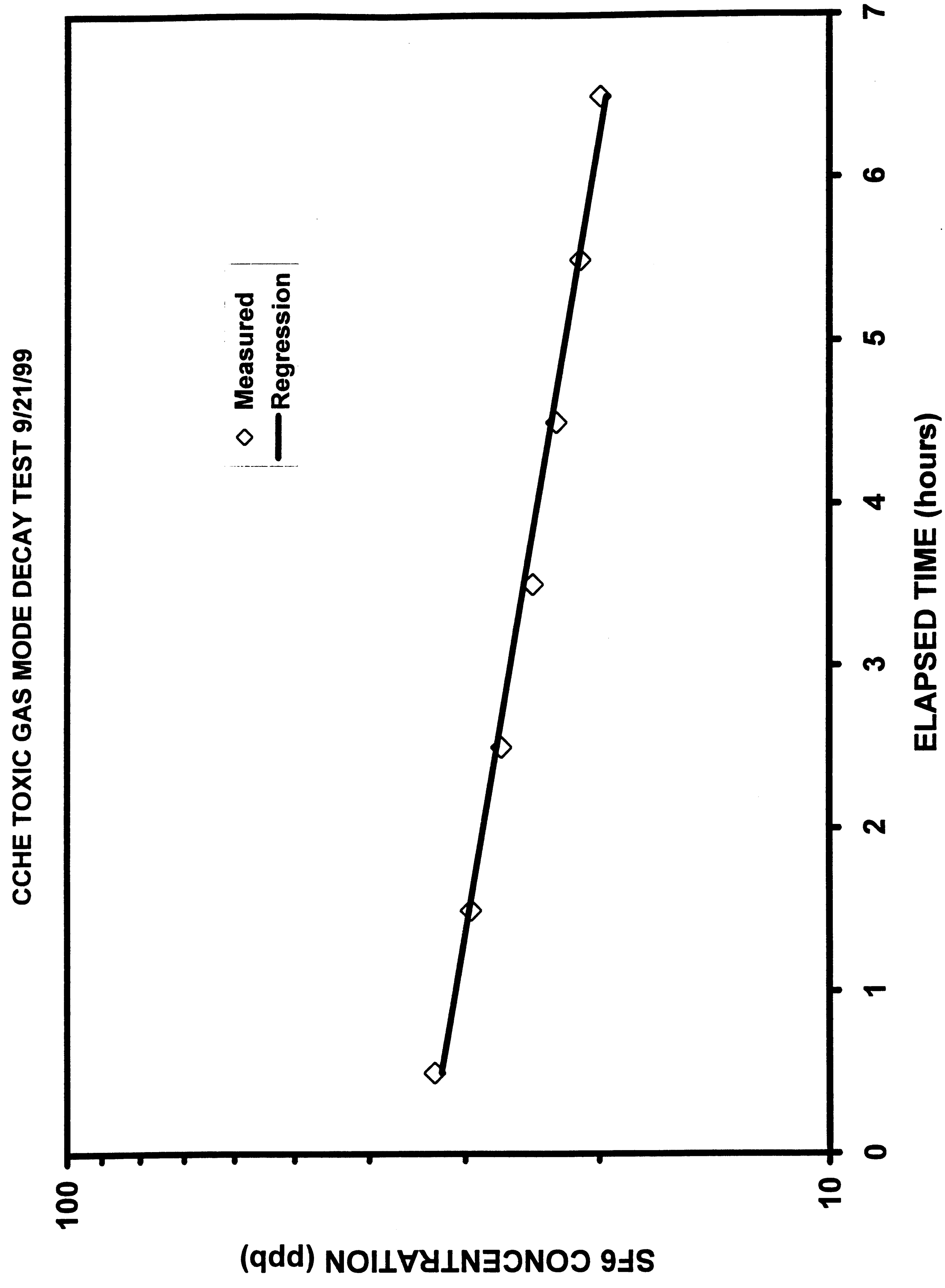

Figure 8. Toxic Gas Mode Tracer Gas Concentration Decay Data 9/21/99

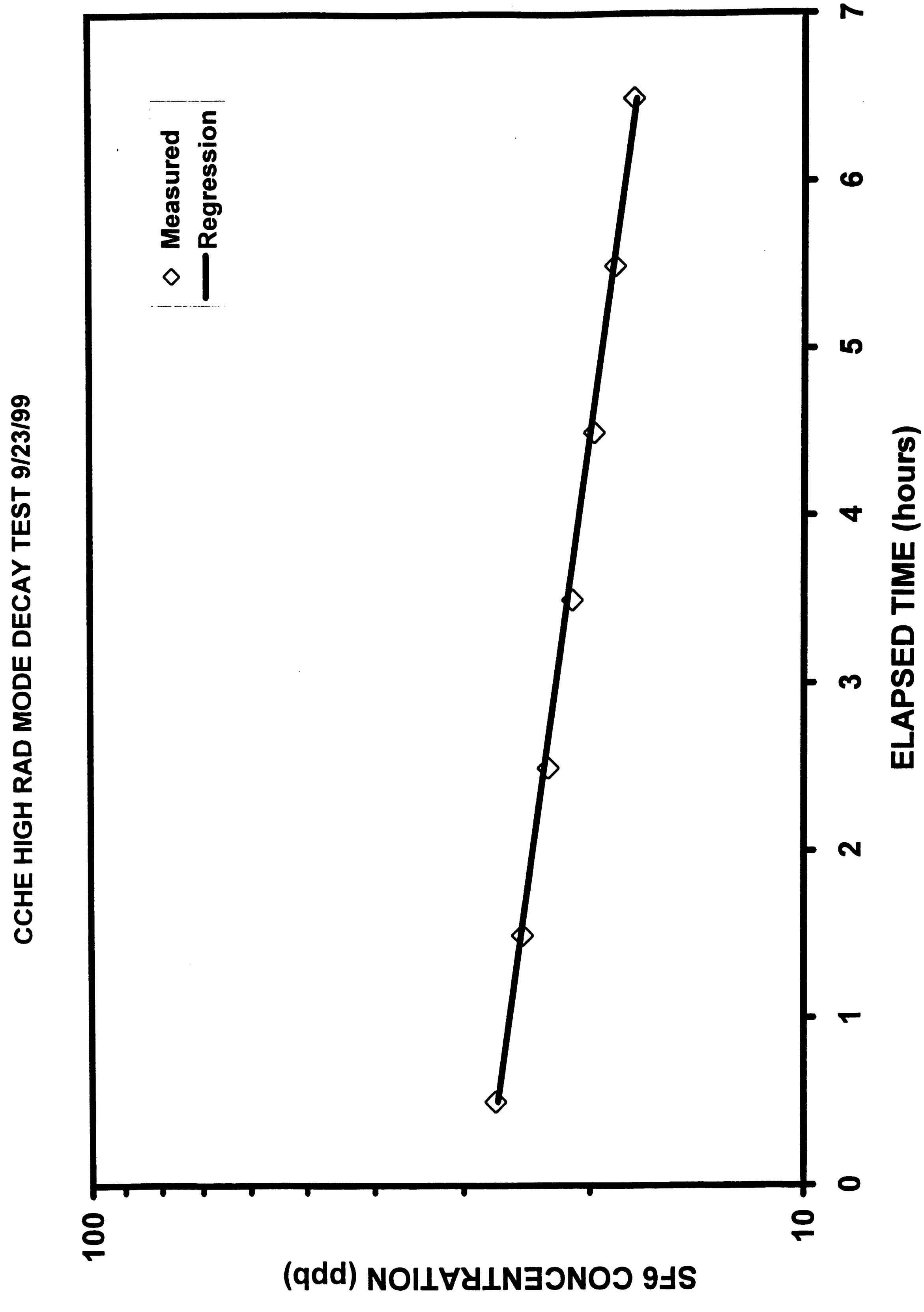

Figure 9. HiRad Mode Tracer Gas Concentration Decay Data 9/23/99